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COMMISSION OF THE EUROPEAN COMMUNITIES

COSTAX-BWR
A NUMERICAL PROGRAMME FOR THE AXIAL DYNAMICS OF BWR NUCLEAR REACTORS

by

G. FORTI

1972

Joint Nuclear Research Centre
Ispra Establishment - Italy

Nuclear Study

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The code performs a complete converged neutronic and thermal steady state calculation, including criticality search according to different options before starting a transient.

Any kind of transient may be simulated: rod drop, loss of coolant flow, inlet enthalpy excursions, or any combination of them.

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ABSTRACT

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KEYWORDS

PROGRAMMING
BOILING WATER REACTORS
I-DIMENSIONAL CALCULATIONS
NEUTRON DIFFUSION EQUATION
THERMODYNAMICS
HEAT TRANSFER
FUEL RODS
PRESSURE
PLATES
COOLANT LOOPS
TRANSIENTS
LOSS OF COOLANT
SHUT DOWN
SUBCOOLED BOILING
VAPOR PRESSURE
FORTRAN
TEMPERATURE
VOID FRACTION

Nomenclature

Latin letters

A Coolant channel cross section

C_p Water specific heat

C Coefficient in Zuber's drift velocity formula

D Hydraulic diameter

G Coolant mass flow rate

h convective heat transfer coefficient

h' Coefficient in boiling heat transfer correlation $\phi_b = h' \Delta T_S^n$

H Specific enthalpy of liquid water

H_v Specific enthalpy of steam

k Bankoff's coefficient

p Heated perimeter - also pressure

q_l Liquid water volume flow rate

q_v Steam volume flow rate

Q Specific power added to coolant (per unit volume)

R Recondensation constant

T Temperature

$\bar{V}_{drift}$ Weighted section average of steam drift velocity

Greek letters

α Void fraction

ΔT_{sur} Heated wall superheating

γ Steam/water density ratio

λ Latent heat of vaporization

ρ Water density

ρ_v Steam density

ϕ Heat flux

ϕ_c Convective heat flux

ϕ_b Boiling heat flux

ψ Steam specific volume source

ψ_S Steam specific volume source at the heated wall

ψ_b	Steam specific volume source in the bulk of the coolant
τ	Bowring's fraction of vapour generating transferred heat

COSTAX-BWR - A Numerical Program for the Axial Dynamics of BWR Nuclear Reactors *)

1. Purpose

The computer code COSTAX-BWR, written in FORTRAN for IBM 360, as described in the present report, is a specialization for BWR of COSTAX-BOIL, and contains further developments and improvements. The reader is referred to the COSTAX-BOIL report /¯1_7 for a general description of the nature and structure of the code.

The time dependent neutron diffusion equations in plane geometry and two energy groups are coupled to the dynamic model of the typical cooling channel, giving a detailed representation of the average axial behaviour of a BWR nuclear reactor. The coupling is done pointwise for both the power source that couples the neutron fluxes to thermal calculations and the thermal feedback that affects the nuclear constants according to fuel temperatures, liquid coolant temperatures and void fractions. The same constant meshing is employed for neutronics and thermohydraulics.

The channel representation includes the heat transmission at each axial level across a cylindrical fuel rod, a gap and a cladding, and the thermohydraulics of the two-phase flow cooling channel.

The two phase kinematic model employed is essentially that of Zuber /¯2_7 while surface heat transmission and subcooled void formation are treated according to the FRANCESCA model worked out by the author /¯3 and 4_7.

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*) Manuscript received on April 5, 1972

COSTAX-BWR is intended for the analysis of those transients of BWR in which the effects of spatial power and void variable distribution are essential for the correct representation of phenomena. For BWR, this includes both accidental situations and severe operational transients, because of the great importance of the interplay between local reactivity, power, and voids. Although an exhaustive analysis of these spatial effects in power-reactors would require calculations with at least two, if not three spatial dimensions, the most relevant effects are already apparent in the axial direction, for the average cooling channel.
(A two dimensional RZ code with parallel channel flow distribution is being developed ar CCR-Ispra and is already operative.)

The treatment of each problem requires the careful determination of the initial steady state condition in which neutron flux axial shape, power profile, and void and temperature distribution are all consistent, taking feedback into account, in a precisely critical situation. This initial condition determination has a practical interest for its own sake, and the program has been designed to be useful also in stationary problems.

2. The Neutron Diffusion Model

The neutron diffusion model is practically identical to the already mentioned COSTAX-BOIL code. For completeness we repeat here the main features of the model.
The two coupled differential equations corresponding to the two energy groups are represented in a finite difference approximation with constant meshes and backwards time differences. The delayed neutron groups are considered as sources in each time step, and the system of coupled linear equations is solved by a direct method of forward elimination and backwards substitution operating with 2 x 2 matrixes. The delayed neutron precursors' concentration evolution is calculated explicitly at each point and time step.

3. The Coolant Channel

Some modifications have been introduced in the channel model with respect to the previous FRANCESCA model. The fuel rod is cylindrical, and is subdivided into concentric shells of equal volume (up to 10) for finite difference representation of heat conduction equations; a gap between fuel and cladding is represented as a fixed thermal resistance, and the cladding is subdivided into two nodes considered to be representative of inner and outer surface temperature. The resulting finite difference equations, with backwards differences in time, give for each axial level a tridiagonal system of linear equations which is transformed by in-out elimination into a linear relation $T_{sur} = a\,\phi + b$ connecting the external temperature of the cladd-ing to the heat flux towards the coolant. The inner cladding and fuel temperatures are obtained by backwards resubstitution when the surface temperature is known. The coefficients of linear terms of the transformed system are permanently determined if the thermal properties of the fuel are constant; they must be reevaluated according to the latest value available for fuel temperatures when the properties are temperature dependent. The known terms of the equations must in any case be calculated at each step, since they depend on temperatures at the beginning of the time step. This section of the model corresponds to the selection of one of the options of the previous program.

The two-phase flow model of the coolant channel has been extended from the previous FRANCESCA model to include the following:

a) General pressure variation with time is considered: the water constants, dependent on pressure, are automatically recomputed by the code at each time step when necessary by simple fittings (validity range 30 to 100 bar). The water properties are always considered at saturation value independently of space, based on general pressure level. The implications of such assumptions have been discussed in the previously mentioned reports, and the approximation is acceptable for BWR reactors as long as we do not consider blow down accidents with pressure wave propagation effects.

b) The two-phase flow model has been extended to include average local vapour drift, according to Zuber's theory [2] besides the effect of concentration distribution, as considered by Bankoff's model. The effect of this drift is negligible in normal flow conditions in forced circulation systems, but may become relevant in low flow conditions as for instance in loss of coolant flow transients. Zuber's relation may be expressed, in terms of the void fraction α, the total volume flow rate w and the vapour volume flow rate q_v as:

$$q_v = \alpha \left(\frac{w}{k} + \bar{V}_{drift} \right)$$

where k is Bankoff's parameter and $\bar{V}_{drift}$ is the weighted section average drift velocity which may be expressed, in bubbly flow condition, according to Zuber, as

$$\bar{V}_{drift} = c \left(\frac{\sigma (1-\gamma)}{\rho \ell} \right)^{1/4} .$$

Adding to this expression the effect of the heated surface's vapour source, according to the formulation given in the previous FRANCESCA model:

$$q_v = \alpha\left(\frac{w}{k} + \overline{V}_{drift}\right) - \frac{Z_e \, \psi_S}{k}$$

or,solving for α

$$\alpha = \frac{kq_v}{w+k\overline{V}_{drift}} + \frac{Z_e \, \psi_S}{w+k\overline{V}_{drift}}$$

Apart from these modifications the general structure of the program is unchanged: we shall therefore describe in some detail only the two-phase flow model.

4. The Two-Phase Flow Model

We shall give here the equations of the model as obtained directly in the finite difference formulation.

Let us consider a segment of channel of height ΔZ during the time interval Δt; we shall admit that the liquid and vapour flowing out of the segment are representative of the whole space and time interval. (This corresponds physically to an infinite turbulent mixing in the interval, and from an analytical point of view to backwards difference scheme in space and time for the corresponding differential equations). With this assumption, and indicating by a star the quantities at the beginning of the time interval, the continuity equations read as follows:

a) Vapour Continuity Equation

$$\Delta Z \ \rho_v \alpha + \Delta t \, \rho_v q_v = Z \rho_v^* \alpha^* + \Delta t \, \rho_{v_{inlet}} \, q_{v_{inlet}} + \Delta Z \ \Delta t \ \psi$$

where ψ is the vapour volumetric source.

Taking into account the "kinematic constitutive equation":

$$\alpha = \frac{k q_v}{w + k\bar{V}_{drift}} + \frac{Z_e \psi S}{w + k\bar{V}_{drift}}$$

it may be written as:

$$q_v = \frac{w+k\bar{V}_{drift}}{w+k\bar{V}_{drift}+k\frac{\Delta Z}{\Delta t}} \left(q_{v_{inlet}} + \psi Z + \frac{\Delta Z}{\Delta t} \frac{\rho_v^*}{\rho_v} \alpha^* - \frac{\Delta Z}{\Delta t} \frac{Z_e \psi S}{w+kV_{drift}} \right)$$

b) Total Mass Continuity Equation

$$\Delta Z \left\{ \rho_v \alpha + \rho_\ell (1-\alpha) - \rho_v^* \alpha^* - \rho_\ell^* (1-\alpha^*) \right\} + \Delta t \left\{ \rho_\ell q_\ell + {}_v q_v - \rho_\ell q_{\ell_{inlet}} - \rho_v q_{v_{inlet}} \right\} = 0$$

taking $\rho_\ell^* = \rho_\ell$ since the liquid density variation with pressure is negligible, remembering that $w = q_v + q_\ell$, and making use of the vapour continuity equation, this gives:

$$w = w_{inlet} + \Delta Z (1-\gamma) \psi - \frac{\Delta Z}{\Delta t} (1 - \frac{\rho_v^*}{\rho_v})$$

c) Energy Continuity Equation

In terms of enthalpy, the energy continuity equation gives the total enthalpy change in the segment during the time interval as equal to the heat added, plus the pressure variation term $V \Delta p$, minus the net enthalpy flow out of the segment.

Referred to the unit cross section this gives:

$$\Delta Z \left\{ H_v \rho_v \alpha + H_\ell \rho_\ell (1-\alpha) - H_v^* \rho_v^* \alpha^* - H_\ell^* \rho_\ell (1-\alpha^*) \right\} =$$

$$= Q \Delta t \Delta Z + \Delta p \Delta Z - \Delta t \left\{ \rho_\ell H_\ell q_\ell + \rho_v H_v q_v - \rho_\ell H_{\ell_{inlet}} q_{\ell_{inlet}} - \rho_v q_{v_{inlet}} H_{v_{inlet}} \right\}$$

taking into account the other continuity equations, this gives for the liquid enthalpy the following equation:

$$H = \frac{(Q+\frac{\Delta p}{\Delta t})\,\frac{\Delta Z}{\rho} + q_{\ell_{inlet}} H_{inlet} - \gamma\, H_v\, \Delta Z \psi}{q_\ell + \frac{\Delta Z}{\Delta t}(1-\alpha)} + $$

$$- \frac{\gamma(H_v - H_v^*)\,\frac{\Delta Z}{\Delta t}\,\frac{\rho_v^*}{\rho_v}\alpha^* + \frac{\Delta Z}{\Delta t}(1-\alpha^*)H^*}{q_\ell + \frac{\Delta Z}{\Delta t}(1-\alpha)}$$

This equation is useful when $H < H_{sat}$; if the liquid enthalpy reaches saturation; assuming thermodynamic equilibrium, the energy equation allows to calculate the vapour source ψ as follows:

$$\psi = \frac{1}{\gamma\lambda\Delta Z}\left[(Q+\frac{\Delta p}{\Delta t})\,\frac{\Delta Z}{\rho} - \frac{\Delta Z}{\Delta t}\,(1-\alpha^*)(H_{sat} - H^*) + \right.$$

$$\left. - \frac{\Delta Z}{\Delta t}\,\gamma\,\frac{\rho_v^*}{\rho_v}\alpha^*(H_v - H_v^*) - q_{\ell_{inlet}}(H_{sat} - H_{inlet})\right]$$

These are the continuity equations used; the momentum equation is disconnected from the others in our assumptions, as has been explained in the previous reports. It is employed only to evaluate the pressure drops in the channel.

The other equations of the model are essentially unchanged, and are given for completeness.

In the subcooled boiling region, the vapour source, not specified by the energy equation because there is no thermodynamic equilibrium, is given by the following relations: $\psi = \psi_b + \psi_s$, the source is given by a surface term, at the heated wall, and a bulk term, which is negative and corresponds to recondensation $\psi_s = R\,\alpha(T-T_{sat})$. The recondensation constant R is free, and may be taken as zero, when more precise information is not available, following the suggestion of Bowring, who showed that recondensation is often negligible in practical conditions.

The surface term, always following Bowring, is given by $\psi_s = \tau \frac{p}{A} \frac{\phi_b}{\gamma\rho\lambda}$, where p/A is the ratio of the heated perimeter to the cross section area of the channel, ϕ_b is the heat flux caused by the boiling heat transfer, $\gamma\rho = \rho_v$ and λ is the latent heat of vaporization. τ is an empirical parameter expressing the fraction of the heat that goes into production of bubbles; according to Bowring, it is a constant in the range of pressures of interest and is taken by the code as 0.435.

The boiling heat flux is given, inverting Lottes correlation as $\phi_b = h' \Delta T^n_{sur}$ with $n = 4$ and $h' = 2.54\ 10^{-4}\ e^{0.0632\,p}$ watt/cm^2 $^\circ$C^{-4} (the pressure p is in kg/cm^2).

The condition for inception of nucleate boiling is given as $\Delta T^2_{sur} > \theta\,(T_s - T)$ which gives for the critical surface overheating

$$\Delta T_c = \frac{\theta}{2}\left(1 + \sqrt{1 + 4\ \frac{T_{sat} - T}{\theta}}\ \right)$$

The convective heat transfer is given by the classical relation $\phi_c = h(T_{sur} - T)$ with $\frac{hD}{k} = 0.023$ Reynolds$^{0.8}$ Prandtl$^{0.4}$.

In the local boiling region, the convective heat transfer is linearly reduced from the value $h(T_c - T_\ell) - h'\Delta T_c^n$ to zero when fully developed nucleate boiling occurs. Making use of the Foster and Grief prescription, the relation reads:

$$\phi_c = (h\,(T_c - T) - h'\Delta T_c^n)\left(1 - \frac{T_s - T_c}{\theta_f - \theta}\right) \geq 0 \quad \text{for} \quad T_s > T_c$$

The parameter θ occurring in these expressions represents the overheating of the surface at the inception of nucleate boiling when the liquid is saturated and given by $\theta = (\frac{h}{nh'})^{1/n-1}$.

Accordingly θ_f is given by $\theta_f = 1.4^{1/n}(\frac{h}{h'})^{1/n-1}$.

The relations given above in conjuction with the linear relation $T_{sur} = a\,\phi + b$ resulting from heat conduction in the fuel rod (see page 3), are used for the determination of both T_{sur} and ϕ (and ϕ_s, ϕ_b, ψ_s). In the case of boiling heat transmission this leads to a fourth order equation which is solved numerically by a successive halving method.

Most of the empirical parameters mentioned are defined in the subroutine COEFP of the code, and may easily be modified according to the user's best knowledge. In addition to those already mentioned, we quote the following:

$$\text{Bankoff's } k = 0.815 + 0.185 \; p/p_{critical}$$

This expression is somewhat different from the original Bankoff's correlation and has been found by the author to give acceptable results in practical cases in conjuction with the expression for local drift

$$\bar{V}_{drift} = 2.5 \left(\frac{\sigma(1-\gamma)}{\rho} \right)^{1/4} .$$

The fittings for the water properties are all found in the subroutine WATER, except for liquid water density which is given in the function ROFUN. They have been fitted by rule of thumb methods on tables, and are valid in the range 30 to 100 bar.

The correlations for pressure drops evaluation are rather standard in practical calculations, we shall only mention here the two-phase flow multiplier for local restriction pressure drops, which is given in function TFLM as

$$TFLM = \frac{(1-x)^2}{1-\alpha} + \frac{x^2}{\gamma\alpha^2}$$

5. Output

The output of the program is largely selfexplanatory.
The input data are first printed, then the delayed neutron groups' composition is shown.

A summary of the coolant channel characteristics follows with the results of the thermal calculation corresponding to a flat distribution of power; the pressure drop appears as zero, since the calculation is not yet performed at this stage.

Then the first flux-map is printed, which corresponds to the first initialization step, performed with the feedback corresponding to the flat thermal calculation. The power column is normalized to the average value of the power and the average is given in watt per cm of height of one single average channel. The averages appearing in the DK columns are weighted on the square of power, for easiest comparison with point models.

Then the criticality search results are printed; a complete map of the neutronic and thermal results for the equilibrium state is given. Then the output of the dynamic calculation follows: the printing pattern is freely chosen by the user from three possibilities: complete maps of values, average on regions and global values. In the print of region values FLM1 indicates average fast flux in the region, FLM2 average thermal flux and AVPO average power in regions relative to mean power. By PINT is indicated the total integrated power in Joule. The map of channel results gives for each axial mesh the following items: Power/cm POW, Heat flux FI, vapour quality Q, void fraction VF, temperature of the cladding surface TSUR, inner temperature of the cladding TICL, average temperature of the fuel AVTF, maximum (central point) temperature of the fuel TMAXF and liquid coolant temperature TL. If a riser is present, the void fraction in it is given.

6. Input Form

May problems can be executed in one run. For every problem the first input card is a title, in which any alphamerical information may appear in columns from 7 to 70 included. This title will appear in the output; a 1 in column 6 means that the problem is the last of the run.
A vector of 3500 memory positions DATA (1) to DATA (3500) contains all the data in floating point form (Internal conversion is performed by the code when needed). Since entire groups of memory positions are zero, it is possible to read different sets of significant data; each set must be preceeded by a card containing the integers Ki_1 , Ki_2 defining the first and last datum of the set. Ki_1 and Ki_2 are given in integer form adjusted to the right at columns 12 and 24. The last set of a problem is indicated by - 1 in columns 1 and 2. The data of each set are all in floating form (FORTRAN FORMAT E 12.8). Any number of problems may be run in sequence and only the data changing from the preceding problem need to be given. A title card must be present for each problem. The key to the input is given in appendix A.

7. Computer Specifications and Final Remarks

The program has been written in FORTRAN and compiled on IBM 360/65 in FORTRAN-H by the O.S. 360 level 20.1 (MAY 71). The total program length resulted in 213A8 (exadecimal) bytes. Not very much can be said about execution times, as these depend on many factors. A medium sized problem, requiring a thousand time steps after initialization may take 2 or 3 minutes.

The user of the code is referred to the previous COSTAX BOIL report (EUR 4497 Ref.1), where directions and suggestions for the practical use of the code are given, which apply unchanged to the present program.

The author wishes to thank the AEG methods group, and especially Dr. J. Lockau, who helped with suggestions and criticism in this work, within the framework of the now well-established collaboration between AEG and Euratom.

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[1] G. FORTI
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EUR 4497 (1970)

[2] ZUBER and FINDLAY
Average Volumetric Concentration in Two-Phase Flow Systems
Trans. ASME Jour. of Heat Transfer, Nov. 1965

[3] G. FORTI
A Dynamic Model for the Cooling Channels of a Boiling Nuclear Reactor with Forced Circulation and High Pressure Level
EUR 4052 (1968)

[4] G. FORTI
FRANCESCA - A Dynamic Program for Boiling Cooling Channels
EUR 4241 (1969)

APPENDIX A

Input Key

COSTAX-BWR Input key

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
1	DELT	Δ t for transient calculation	sec	1/15 of minimum expected period generally gives good results.
2	DZ	Δ Z mesh width	cm	
3	IMAX	Number of mesh points	-	up to 100 (including extrapolated boundaries)
4	NREG	Number of regions	-	up to 12
5	NRIT	Number of delayed neutron groups		up to 10
6	IDST	Number of steps for initialization	-	30 is suggested
7	ITCR	Put always 1	-	
8	IDIR	Search indicator - 1 Search for δK_{eff} 0 Poison search 1 Control rods inserted from top (entry of the coolant) 2 Control rods inserted from bottom	-	

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
9	SI	Area of the core cross section	cm^2	This value is employed to normalize the neutronic fluxes to the given total power for the whole reactor
10	BU	Transversal Buckling	cm^{-2}	
11	DELT	Δ t for initialization	sec	10^{-4} is suggested
12	POWER	Steady state power of the reactor	watt	
13	ICAN	Number of channels in the core. The power given to the average channel will be PØWER/ICAN	-	Put 0 if no channel calculation is wanted
14	KPC	Thermal calculation will be made every KPC neutronic time steps	-	Omit if no channel is represented
15	IDOP	Doppler feedback indicator 0 $\delta K_D=b(e^{a(\sqrt{T}-\sqrt{To})}-1)e^{(DATA(19)\times\alpha)}$ -1 $\delta K_D=a(T-T_o)+b(T-T_o)^2$ +1 $\delta K_D=a(\sqrt{T}-\sqrt{T_o})$	-	Only if ICOEF (DATA 18)=0
16	TDOPP	Reference temperature T_o of the fuel for Doppler feedback	°C	

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
17	TREF	Reference temperature for liquid coolant temperature feedback	°C	
18	ICOEF	0 Feedback as δk 1 Feedback affecting all constants		
19		Coefficient in void dependent Doppler feedback (see DATA (15))		
31-40	BETA	β_i Delayed neutrons precursors yield per fission	-	
41-50	DLI	λ_i Delayed neutron precursors decay constants	sec^{-1}	
61-73	I1, I2	Region boundary mesh numbers	-	The first value must be 1 and the last IMAX

REGIONS CONSTANTS

First region

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
81	D1	D_f Fast group diffusion coefficient	cm	
82	SA1	Σ_{af} Fast absorption cross section	cm^{-1}	
83	SSD	Σ_{sd} Slowing down cross section from fast to thermal	cm^{-1}	
84	SF1	$\nu\Sigma_{f_1}$ Fast neutron production cross section	cm^{-1}	
85	W	Fast group neutron velocity	cm/sec	
86	PFAC1	$E_1 \Sigma_{f_1}$ Fission energy production cross section for group 1	joule/cm	
87	D2	D_{th} Thermal group diffusion coefficient	cm	
88	SA	Σ_{a_2} Thermal group absorption cross section	cm^{-1}	
89	SF	$\nu\Sigma_{f_2}$ Thermal neutron production cross section	cm^{-1}	
90	V	Thermal group neutron velocity	cm/sec	
91	$PFAC_2$	$E_2 \Sigma_{f_2}$ Fission energy production cross section - group 2	joule/cm	

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
92	-	Not used		
93-104		Same constants for second region etc...		

Only for ICAN > 0
Omit if no coolant channel is present-Neutronic calculation will be executed without feedback

Feed-back coefficients

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
300	ICI	If 0 the feedback coefficients are equal in all the regions. If 1 they are given regionwise		
301	ALDOP	a in Doppler feedback formula (omit if ICOEF = 1)		see Data (15)
302	BEDOP	b in Doppler feedback formula (omit if ICOEF = 1)		Units dependent on Formula-Temperature in Kelvin or °C
303	AVOID	a in void feedback formula $\delta k_V = a\alpha + b\alpha^2$ omit if ICOEF=1 omit if DATA400=1 (tabulated void feedback)		May be omitted, if the void feedback is given as a table (see DATA (1000))
304	BVOID	b in void feedback formula same as above		
305	ACOCO	a in liquid coolant temperature feedback $\delta k_T = a(T-TREF) + b(T-TREF)^2$	$°C^{-1}$	
306	BCOCO	b in coolant feedback formula	$°C^{-2}$	
307-312		Same for 2nd region etc...		Only if DATA (300) > 0
400		Void feedback indicator 0 quadratic formula 1 tabulated reactivity		

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
450	ICORE	Mesh number of the beginning of the core	-	First node of the active channel, if channel is present. If omitted, the code will take 1
451	NCORE	Mesh number of the end of the core		If omitted, the code will take IMAX

Channel data (indicators)

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
452	NF	Number of radial meshes in the fuel for thermal conduction	–	
453	IVAR	Fuel thermal properties indicator 0 = constant properties 1 = properties temperature dependent		
454	–	Dummy		
455	IVIN	0 inlet mass flow rate calculated during transient 1 inlet mass flow rate given in input " "		
456	IEX	0 external driving pressure by pump characteristics 1 driving pressure given in input		Only if IVIN = 0
457	–	Dummy		
458	IPRESS	Pressure — Perturbation indicators 0 = no perturbation		
459	IVINL	Mass flow rate — 1 = step at time 0 $f(o)^{+} = f(o)\ (1+C2)$		up to 5^{th} order
460	ITIN	Inlet enthalphy — 2 = Polynomial function of time 3 = Sinusoid		
461	IPEX	External driving pressure — $f(t)=f(o)(1+C2 \sin C3t)$ 4 = time table (50 points max.)		

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
462	IP1	Full channel map editing every IP1 printing steps		
463-474	KKC(I)	Mesh numbers in which a local flow resistance exists (12 points maximum)		

Channel data (floating)

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
501	PRESSO	Pressure in steady state condition	bar	
502	DIAH	Hydraulic diameter	cm	
503	FRDF	Fraction of power directly added to coolant (γ rays and neutron moderation)	-	
504	GR	Gravity cosinus (+1 for upwards flow)	-	if omitted, the code will take + 1
505	ZE	Relaxation parameter for void profile in diabatic flow	cm	Omit lacking information
506	PS	Printing time step for channel (restricted point)	sec	
507	A	Coolant cross section area	cm^2	
508	DIAF	Fuel pellet diameter	cm	
509	GAPTH	Thickness of the gap	cm	
510	CLTH	Thickness of the cladding (must not be zero)	cm	
511	ROF	Fuel density	gr/cm^3	
512	CPF	Fuel specific heat (reference temperature value if variable)	Joule/gr°C	

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
513	AKF	Fuel thermal conductivity (reference temp. value if variable)	watt./cm°C	
514	RGAP	Gap thermal resistance	cm^2 °C/watt	
515	ROCL	Cladding density	gr/cm^3	
516	CPCL	Cladding specific heat	Joule/gr °C	
517	AKCL	Cladding thermal conductivity	watt/cm °C	
518	TINERO	Total inertia of the channel (if omitted the code will take the total lenghth (ZCORE+ZIN+ZRIS1+ZRIS2)	cm	Needed only if IVIN = 0
519	HINLET	Inlet enthalpy of coolant	Joule/gr	
520	QINLET	Total mass flow in the reactor in steady state (will be divided by ICAN to get the single channel mass flow)	Kg/sec	Omit if exit quality is imposed
521	FFK	Active channel friction coefficient ($\Delta p = \frac{\Delta z}{2} \frac{FFK}{Dh} G^2/\rho$)	-	
522	R1	Recondensation constant for subcooled zone If omitted, no recondensation is considered.	$(sec\ °C)^{-1}$	5. has been found to give good results

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
523	XOUT	Imposed exit quality for the steady state	-	if omitted, it will be calculated by the code according to the given power and mass flow
524	DPEQ	Imposed pressure drop for the steady state (the code will calculate the inlet orificing accordingly)	bar	If omitted, it will be evaluated by the code
525	AFRIC	Dummy		
526	BFRIC	Dummy		
527	ALOC	Dummy		
528	BLOC	Dummy		
529	ZIN	Inlet pipe height	cm	
530	CFFI	Inlet friction coefficient $\Delta p=\text{CFFI}\,\frac{1}{2}\rho v^2$	-	
531	ZRIS1	Riser 1 height (if omitted, no riser)	cm	
532	ARIS1	Riser 1 flow area	cm^2	
533	CFRF1	Riser 1 friction coefficient ($\Delta p=\frac{1}{2}\,\text{CFRF1}\;G^2/\rho$)	-	

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
534	AFR1	Dummy		
535	BFR1	Dummy		
536	-	Dummy		
537	ZRIS2	Riser 2 height (if omitted, no riser 2)	cm	
538	ARIS2	Riser 2 flow area	cm^2	
539	CFRF2	Riser 2 friction coefficient ($\Delta p=\frac{1}{2}$ CFRF2 G^2/ϱ)		
540		Dummy		
541		Dummy		
542		Dummy		
543	TKF	To } in formula $K = k_o[1+a(T-To)+b(T-To)^2]$ for fuel variable heat conductivity	°C	Only if IVAR = 1
544	AKF1	a	$°C^{-1}$	If To is omitted
545	AKF2	b	$°C^{-2}$	the corresponding
546	TCPF	To } in same formula for variable specific heat	°C	property is taken
547	CPF1	a	$°C^{-1}$	as constant
548	CPF2	b	$°C^{-2}$	

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
549 550	APEX BPEX	a } Coefficients for external driving pressure b } DPEX = $\Delta p_o + a \Delta v + b \Delta v^2$ Δv is the inlet velocity variation from steady state conditions (cm/sec) and pressure is given in dyne/cm^2		Only if IVIN = 0 and IEX = 0

Perturbation coefficients

Only if the corresponding options are checked (indicators = 1,2, or 3)

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
551-556	CPRESS	Pressure coefficients		The first coefficient of each group represents the nominal value for time 0 (if different from zero the code will replace this value to the value given before, if zero the preceeding value will be kept). The 5 following coefficients are interpreted according to the option checked (see DATA 458,459,460,461).
557-562	CVIN	Mass flow coefficients		
563-568	CTIN	Inlet enthalpy coefficients		
569-574	CPEX	External driving pressure coefficients		
575 to 586	CKFF(I)	Local friction coefficients $\Delta p_{loc} = CKFF\ \frac{1}{2}\ G^2/\ell$ corresponding to the selected meshes (see KKC $\equiv$ DATA 463 ff)		
578 to 600		Dummy		

Perturbation time Tables

Only when the corresponding options are checked (indicators = 4)

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
601 to 650 651 to 700	HTAB	Inlet enthalpy $\begin{cases} \text{times} \\ \text{values relative to nominal} \end{cases}$	sec –	Each time table is built as 50 values of time (the first must be 0) followed by 50 values for the variable (relative values to the nominal shall be given). Any number of values may be given, the variable will be kept constant at the latest value after the last time given.
701–800	QTAB	Mass flow (same)		
801–900	PTAB	Pressure		
901–1000	PEXTAB	External driving pressure		

Void feedback coefficients

δk feedback	ICOEF = 0 DATA(400) = 1	Feedback on all constants			
1001 to 1020	Give 20 values of δk corresponding to α = 0.05, 0.1,.... 1.0	1001	ALD1	a	in formula $D1 = D1(1+a\alpha + b\alpha^2)$
		1002	ALD2	b	
1021 to 1040	Same for 2nd region if DATA (300) = 1.	1003	ALSSD	a	in same formula for Σ_{sd}
		1004	BESSD	b	
	etc.	1005	ALSF1	a	in formula for $\nu\Sigma_{f1}$
		1006	BESF1	b	
		1007	ALD2	a	in formula for D_2
		1008	BED2	b	
		1009	ALSA	a	in formula for Σ_{a_2}
		1010	BESA	b	
		1011	ALSF	a	in formula for $\nu\Sigma_{f_2}$
		1012	BESF	b	

	1013	ALFAD	α_D	in formula for fast absorption cross section $\Sigma_{a_1} = \Sigma_{a_1 ref}\left\{1. + \alpha_D\left(\sqrt{T_f}-\sqrt{T_{ref}}\right) + \alpha_1\left(T_f - T_{ref}\right) + \alpha_2\left(T_f - T_{ref}\right)^2 + \alpha_3\alpha + \alpha_4\alpha^2 + \alpha_5\alpha\left(T_f - T_{ref}\right)\right\}$
	1014	ALF1	α_1	
	1015	ALF2	α_2	
	1016	ALF3	α_3	
	1017	ALF4	α_4	
etc.	1018	ALF5	α_5	
	1019	-		Dummy
	1020	-		
	1021 to 1040 etc.			Idem 2^{nd} region if DATA (300) = 1

Criticality search parameters

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
1600	LF	Maximum number of trials for search		50 is suggested
1601	DAPF	Convergence criterium for search (10^{-3}) Reciprocal of period will be less than DAPF		
1602	SPRG	Second guess of control parameter for search (Σa_2, cm of rod insertion, or δk)		First guess is zero
1603	SPB	Σp_2 corresponding to control rods	cm^{-1}	Only if banked rods (IDIR=1,2)
1604	RFAST	Ratio $\Sigma_{p_1}/\Sigma_{p_2}$ for poison		Not used if IDIR = -1 (K_{eff} search)
1605 to 1616	KV(I)	I if poison is present in region I O if it is not		Only when diluted poisons search is done (IDIR = O)

Nuclear perturbation parameters

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
1617	IDKF	0 perturbation is given as absorption cross section -1 perturbation given as δk		
1618	IDIR	0 perturbation is diffused 1 banked rod perturbation from top 2 banked rod perturbation from bottom		
1619	RFAST	Ratio Σ_{p1}/Σ_{p2} for absorption perturbation		Only if IDKF = 0
1620	SPB	Control rod Σ_{p2} (or δk if IDKF = -1) for perturbation	cm^{-1} or δk	Only if IDIR = 1,2
1621 to 1699	TBAR	Successive times for perturbation insertion	sec	
1700	VBAR	Time zero insertion for perturbation parameter		The parameter may represent depth of insertion (cm) of rods, or Σ_{p2}, or δk, according to the options checked. See directions and suggestions page of the text.
1701 to 1779	VBAR	Insertion values for successive times		
1781 to 1792		Factors which multiply the value VBAR(t) in each region I		Considered only if IDIR = 0

Printing specifications

DATA N°	NAME	DESCRIPTION	UNIT	REMARKS
1851+6n		Final time for the n^{th} printing pattern	Sec	n = 0, 1, etc.. As many cards as wanted may be given, allowing successive printing patterns.
1852+6n		Time step for the more frequent type of print	Sec	
1853+6n	I1S	Type of more frequent output 1. only power, average fluxes and period 2. complete map of fluxes and delayed neutron precursors concentration 3. same as 1 plus region averages 4,5 no print		After the last is completed the calculation stops and a final print is done. Then the control is transferred to the beginning of the programme to start a new problem, unless the title card contains a positive integer in column 1-6, in which case the run is stopped
1854+6n		Time step for the less frequent type of print must be multiple of I1P and divisor of KTP)	sec	
1855+6n	I2S	Same as I1S for less frequent output		
1856+6n	-	Not used END of DATA		

APPENDIX B

A collection of channel model equations

Appendix B

A collection of channel model equations

Continuity

0) $w = q_v + q_\ell$

1) $w = w_{inlet} + \Delta z\,(1-\gamma)\,\psi - \frac{\Delta z}{\Delta t}\,(1-\frac{\rho_v^*}{\rho_v})\,\alpha^*$

2) $q_v = \frac{w+k\bar{V}_{drift}}{w+k\bar{V}_{drift} + k\,\frac{\Delta z}{\Delta t}}\left(q_{v_{inlet}} + \psi\Delta z + \frac{\Delta z}{\Delta t}\,\frac{\rho_v^*}{\rho_v}\,\alpha^* - \frac{\Delta z}{\Delta t}\,\frac{z_e\,\psi_s}{w+k\bar{V}_{drift}}\right)$

3a) $H = \frac{(Q+\frac{\Delta P}{\Delta t})\,\frac{\Delta z}{\ell} + q_{\ell\ inlet}\,H_{inlet} - \gamma H_v \Delta z \psi - \gamma\,(H_v - H_v^*)\,\frac{\Delta z}{\Delta t}\,\frac{\rho_v^*}{\rho_v}\,\alpha^* + \frac{\Delta z}{\Delta t}\,(1-\alpha^*)\,H^*}{q_\ell + \frac{\Delta z}{\Delta t}\,(1-\alpha)}$

3b) $\psi = \frac{1}{\gamma\lambda\Delta z}\left[(Q+\frac{\Delta P}{\Delta t})\,\frac{\Delta z}{\rho} - \frac{\Delta z}{\Delta t}\,(1-\alpha^*)(H_{sat}-H^*) - \frac{\Delta z}{\Delta t}\,\gamma\frac{\rho_v^*}{\rho_v}\,\alpha^*(H_v - H_v^*) + \right.$

$\left. - q_{\ell_{inlet}}\,(H_{sat} - H_{inlet})\right]$

Vapour source correlations

0a) $\psi = \psi_s + \psi_b$

1a) $\psi_b = R_\alpha\,(T - T_{sat})$

2) $\psi_s = \tau\,\frac{P}{A}\,\frac{\emptyset b}{\ell\gamma\lambda}$

Heat flux correlations

0) $\phi = \phi_c + \phi_b$

1) $\phi_c = h\,(T_{sur} - T)$ for $T_{sur} < \Delta T_c + T_{sat}$

1a) $\phi_c = \left[h\,(T_c - T) - h'\,\Delta T_c^n \right] \left(1 - \frac{\Delta T_{sur} - \Delta T_c}{\theta_f - \theta}\right) \geq 0$ for $T_{sur} \geq \Delta T_c + T_{sat}$

2) $\phi_b = 0$ for $T_{sur} < \Delta T_c + T_{sat}$

2a) $\phi_b = h'\,\Delta T_{sur}^n$ for $T_{sur} \geq \Delta T_c + T_{sat}$

3) $\Delta T_c = \frac{\theta}{2} \left(1 + \sqrt{1 + 4\,\frac{T_{sur} - T}{\theta}} \right)$

4) $\theta = \left(\frac{h}{nh'} \right)^{\frac{1}{n-1}}$

APPENDIX C

Sample Problem Output

COSTANZA AXIAL-BOILING CHANNEL
T.C.R. EURATOM ISPRA

SAMPLE PROBLEM FOR COSTAX-BWR

1	0.100000E-01	2	0.160000E 02	3	0.270000E 02	4	0.600000E 01	5	0.600000E 01	6	0.300000E 02
7	0.100000E 01	8	-0.100000E 01	9	0.450000E 05	10	0.100000E-03	11	0.100000E-03	12	0.500000E 09
13	0.100000E 05	14	0.500000E 01	15	0.100000E 01	16	0.286000E 03	17	0.286000E 03	18	0.0
31	0.214000E-03	32	0.142000E-02	33	0.127000E-02	34	0.256000E-02	35	0.750000E-03	36	0.273000E-03
41	0.124000E-01	42	0.305000E-01	43	0.111000E 00	44	0.301000E 00	45	0.113000E 01	46	0.300000E 01
61	0.100000E 01	62	0.400000E 01	63	0.900000E 01	64	0.140000E 02	65	0.190000E 02	66	0.240000E 02
67	0.270000E 02										
81	0.220000E 01	82	0.600000E-03	83	0.743999E-01	84	0.0	85	0.110000E 10	86	0.0
87	0.300000E 00	88	0.120000E-01	89	0.0	90	0.400000E 06	91	0.0	92	0.0
93	0.220000E 01	94	0.140000E-01	95	0.360000E-01	96	0.670000E-02	97	0.110000E 10	98	0.859999E-13
99	0.430000E 00	100	0.660000E-01	101	0.850000E-01	102	0.400000E 06	103	0.110000E-11	104	0.0
105	0.220000E 01	106	0.140000E-01	107	0.360000E-01	108	0.670000E-02	109	0.110000E 10	110	0.859999E-13
111	0.430000E 00	112	0.640000E-01	113	0.850000E-01	114	0.400000E 06	115	0.110000E-11	116	0.0
117	0.220000E 01	118	0.140000E-01	119	0.360000E-01	120	0.670000E-02	121	0.110000E 10	122	0.859999E-13
123	0.430000E 00	124	0.620000E-01	125	0.850000E-01	126	0.400000E 06	127	0.110000E-11	128	0.0
129	0.220000E 01	130	0.140000E-01	131	0.360000E-01	132	0.670000E-02	133	0.110000E 10	134	0.859999E-13
135	0.430000E 00	136	0.600000E-01	137	0.850000E-01	138	0.400000E 06	139	0.110000E-11	140	0.0
141	0.220000E 01	142	0.600000E-03	143	0.743999E-01	144	0.0	145	0.110000E 10	146	0.0
147	0.300000E 00	148	0.100000E-01	149	0.0	150	0.400000E 06	151	0.0	152	0.0
301	-0.100000E-03	302	0.0	303	-0.500000E-01	304	-0.100000E 00	305	-0.500000E-03	306	0.0
450	0.400000E 01	451	0.240000E 02	452	0.500000E 01	453	0.0	454	0.0	455	0.100000E 01
456	0.0	457	0.0	458	0.0	459	0.0	460	0.400000E 01	461	0.0
462	0.500000E 01										
501	0.700000E 02	502	0.125000E 01	503	0.0	504	0.0	505	0.0	506	0.500000E 00
507	0.180000E 01	508	0.125000E 01	509	0.0	510	0.900000E-01	511	0.100000E 02	512	0.350000E 00
513	0.230000E-01	514	0.170000E 01	515	0.650000E 01	516	0.290000E 00	517	0.130000E 00	518	0.0
519	0.123000E 04	520	0.0	521	0.130000E-01	522	0.0	523	0.930000E-01	524	0.0
529	0.150000E 02	530	0.500000E 02	531	0.200000E 02	532	0.180000E 01	533	0.200000E 01		
601	0.0	602	0.500000E 01								
651	0.100000E 01	652	0.980000E 00								
1600	0.500000E 02	1601	0.100000E-01	1602	-0.100000E-01						
1851	0.100000E 02	1852	0.200000E 00	1853	0.100000E 01	1854	0.100000E 01	1855	0.200000E 01	1856	0.0

```
      BETA              LAMBDA

    0.21400E-03      0.12400E-01
    0.14200E-02      0.30500E-01
    0.12700E-02      0.11100E 00
    0.25600E-02      0.30100E 00
    0.75000E-03      0.11300E 01
    0.27300E-03      0.30000E 01

VOID AND DOPPLER FEEDBACK AS DK
   DK DOPPLER=A.(SQRT T-SQRT TDOP)
   DK VOID=A.VF+B.VF.VF

  REGION  1
DFAST  0.22000E 01 SR  0.75000E-01 SSD  0.74400E-01 NUSF1  0.0
DTHER  0.30000E 00 SA  0.12000E-01 NUSF  0.0

FEEDFACK COEFFICIENTS
  COOLANT TEMPERATURE   A -0.50000E-03   B  0.0
  DOPPLER    A -0.10000E-03   B  0.0
     VOID    A -0.50000E-01   B -0.10000E 00

  REGION  2
DFAST  0.22000E 01 SR  0.50000E-01 SSD  0.36000E-01 NUSF1  0.67000E-02
DTHER  0.43000E 00 SA  0.66000E-01 NUSF  0.85000E-01

FEEDFACK COEFFICIENTS
  COOLANT TEMPERATURE   A -0.50000E-03   B  0.0
  DOPPLER    A -0.10000E-03   B  0.0
     VOID    A -0.50000E-01   B -0.10000E 00

  REGION  3
DFAST  0.22000E 01 SR  0.50000E-01 SSD  0.36000E-01 NUSF1  0.67000E-02
DTHER  0.43000E 00 SA  0.64000E-01 NUSF  0.85000E-01

FEEDFACK COEFFICIENTS
  COOLANT TEMPERATURE   A -0.50000E-03   B  0.0
  DOPPLER    A -0.10000E-03   B  0.0
     VOID    A -0.50000E-01   B -0.10000E 00

  REGION  4
DFAST  0.22000E 01 SR  0.50000E-01 SSD  0.36000E-01 NUSF1  0.67000E-02
DTHER  0.43000E 00 SA  0.62000E-01 NUSF  0.85000E-01

FEEDFACK COEFFICIENTS
  COOLANT TEMPERATURE   A -0.50000E-03   B  0.0
  DOPPLER    A -0.10000E-03   B  0.0
     VOID    A -0.50000E-01   B -0.10000E 00

  REGION  5
DFAST  0.22000E 01 SR  0.50000E-01 SSD  0.36000E-01 NUSF1  0.67000E-02
DTHER  0.43000E 00 SA  0.60000E-01 NUSF  0.85000E-01
```

```
FEEDFACK COEFFICIENTS
  COOLANT TEMPERATURE   A -0.50000E-03   B  0.0
  DOPPLER   A -0.10000E-03   B  0.0
     VOID   A -0.50000E-01   B -0.10000E 00

  REGION  6
DFAST  0.22000E 01 SR  0.75000E-01 SSD  0.74400E-01 NUSF1  0.0
DTHER  0.30000E 00 SA  0.10000E-01 NUSF  0.0

FEEDFACK COEFFICIENTS
  COOLANT TEMPERATURE   A -0.50000E-03   B  0.0
  DOPPLER   A -0.10000E-03   B  0.0
     VOID   A -0.50000E-01   B -0.10000E 00
```

```
                                        FUEL DATA
 FUEL RADIUS        DENSITY          MASS/CM     CLAD RADIUS      EXT.RADIUS
 0.62500E 00     0.10000E 02     0.12272E 02     0.62500E 00     0.71500E 00


  TEMPERATURE INDEPENDENT CONSTANTS

     CPF              KF             CPCL             KCL
0.350000E 00    0.230000E-01    0.290000E 00    0.130000E 00
```

STATIC CALCULATION

```
CHANNEL DATA
 HEIGHT      320.0 CM    SECTION      1.800 CM2    COOLANT DENSITY    0.73970 G/CM3    PRESSURE    70.0000 BAR
 INLET PIPE HEIGHT        15.0
 RISER 1 HEIGHT      20.0  RISER 2      0.0
 TOTAL CHANNEL POWER IN FUEL     0.50000E 05 WATT
 TOTAL CHANNEL POWER IN COOLANT 0.0          WATT

 IMPOSED EXIT QUALITY    0.09300


 INLET MASS FLOW 0.28913E 03 GR/SEC
 INLET VELOCITY /VINLET/=    217.15068 CM/SEC
 EXIT QUALITY /XOUT/=    0.09300
 AVERAGE VOID FRACTION /AVF/=    0.33356
 POWER FLOW TO COOLANT /TPF/= 0.50000E 05 WATT
 POWER OUTPUT 0.50000E 05
 INLET TEMPERATURE /TINLET/=     279.62

 PRESSURE DROP      0.0      BAR
  INLET         0.0          CHANNEL      0.33225             RISER              0.0
  FRICTION      0.13212      GRAVITY      0.15843             SPACE ACCEL.       0.04170

 HEAT TRANSFER CONSTANTS
   HC 0.18157E 01            HB 0.23123E-01                   TETA       2.70                TETAF       4.66
   ZE       0.0              R1 0.0                           BANKOFF K 0.87352
```

I	POW	FI	Q	VF	TSUR	TICL	AVTF	TMAXF	TL
1	0.15625E 03	0.34780E 02	-0.15832E-01	0.37301E-01	0.29202E 03	0.31772E 03	0.67235E 03	0.92751E 03	0.28054E 03
2	0.15625E 03	0.34780E 02	-0.10105E-01	0.70978E-01	0.29199E 03	0.31768E 03	0.67231E 03	0.92748E 03	0.28147E 03
3	0.15625E 03	0.34780E 02	-0.43772E-02	0.10227E 00	0.29199E 03	0.31769E 03	0.67232E 03	0.92748E 03	0.28242E 03
4	0.15625E 03	0.34780E 02	0.13512E-02	0.13201E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28334E 03
5	0.15625E 03	0.34780E 02	0.70793E-02	0.15966E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28428E 03
6	0.15625E 03	0.34780E 02	0.12808E-01	0.18543E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28522E 03
7	0.15625E 03	0.34780E 02	0.18536E-01	0.22083E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
8	0.15625E 03	0.34780E 02	0.24264E-01	0.26909E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
9	0.15625E 03	0.34780E 02	0.29992E-01	0.31111E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
10	0.15625E 03	0.34780E 02	0.35720E-01	0.34803E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
11	0.15625E 03	0.34780E 02	0.41448E-01	0.38072E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
12	0.15625E 03	0.34780E 02	0.47176E-01	0.40987E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
13	0.15625E 03	0.34780E 02	0.52904E-01	0.43603E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
14	0.15625E 03	0.34780E 02	0.58632E-01	0.45962E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
15	0.15625E 03	0.34780E 02	0.64360E-01	0.48103E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
16	0.15625E 03	0.34780E 02	0.70088E-01	0.50052E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
17	0.15625E 03	0.34780E 02	0.75816E-01	0.51835E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
18	0.15625E 03	0.34780E 02	0.81544E-01	0.53473E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
19	0.15625E 03	0.34780E 02	0.87272E-01	0.54982E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03
20	0.15625E 03	0.34780E 02	0.93000E-01	0.56377E 00	0.29203E 03	0.31772E 03	0.67235E 03	0.92752E 03	0.28580E 03

RISER1 VF= 0.0

FUEL TEMPERATURE MAP

1	927.51	774.60	662.67	552.97	443.98
2	927.48	774.57	662.63	552.93	443.94
3	927.48	774.58	662.64	552.94	443.95
4	927.52	774.61	662.68	552.98	443.99
5	927.52	774.61	662.68	552.98	443.99
6	927.52	774.61	662.68	552.98	443.99
7	927.52	774.61	662.68	552.98	443.99
8	927.52	774.61	662.68	552.98	443.99
9	927.52	774.61	662.68	552.98	443.99
10	927.52	774.61	662.68	552.98	443.99
11	927.52	774.61	662.68	552.98	443.99
12	927.52	774.61	662.68	552.98	443.99
13	927.52	774.61	662.68	552.98	443.99
14	927.52	774.61	662.68	552.98	443.99
15	927.52	774.61	662.68	552.98	443.99
16	927.52	774.61	662.68	552.98	443.99
17	927.52	774.61	662.68	552.98	443.99
18	927.52	774.61	662.68	552.98	443.99
19	927.52	774.61	662.68	552.98	443.99
20	927.52	774.61	662.68	552.98	443.99

TIME 0.0 IT 0 POWER 0.50000E 09

	FLUX1	FLUX2	POWER	ROD VALUE	DKFBACK	DKVOID
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.30362D 11	0.22270D 12	0.0	0.0	0.0	0.0
3	0.32648D 12	0.15984D 13	0.0	0.0	0.0	0.0
4	0.34803D 13	0.43776D 13	0.15892E 00	0.0	0.17786E-04	-0.20042E-02
5	0.90288D 13	0.46775D 13	0.21717E 00	0.0	-0.25000E-02	-0.40527E-02
6	0.14104D 14	0.72243D 13	0.31388E 00	0.0	-0.50776E-02	-0.61597E-02
7	0.19465D 14	0.99672D 13	0.42084E 00	0.0	-0.77257E-02	-0.83433E-02
8	0.25544D 14	0.13082D 14	0.55022E 00	0.0	-0.10381E-01	-0.10532E-01
9	0.32944D 14	0.17082D 14	0.69840E 00	0.0	-0.13028E-01	-0.12710E-01
10	0.40509D 14	0.21266D 14	0.83093E 00	0.0	-0.16528E-01	-0.15918E-01
11	0.46454D 14	0.24392D 14	0.93743E 00	0.0	-0.21306E-01	-0.20696E-01
12	0.51644D 14	0.27119D 14	0.10424E 01	0.0	-0.25845E-01	-0.25235E-01
13	0.57418D 14	0.30161D 14	0.11797E 01	0.0	-0.30124E-01	-0.29514E-01
14	0.65252D 14	0.34721D 14	0.13425E 01	0.0	-0.34141E-01	-0.33531E-01
15	0.72788D 14	0.39239D 14	0.14635E 01	0.0	-0.37903E-01	-0.37293E-01
16	0.76865D 14	0.41455D 14	0.15230E 01	0.0	-0.41423E-01	-0.40813E-01
17	0.78825D 14	0.42522D 14	0.15558E 01	0.0	-0.44717E-01	-0.44107E-01
18	0.80163D 14	0.43267D 14	0.15987E 01	0.0	-0.47800E-01	-0.47190E-01
19	0.82209D 14	0.44968D 14	0.16245E 01	0.0	-0.50688E-01	-0.50078E-01
20	0.80872D 14	0.44839D 14	0.15319E 01	0.0	-0.53397E-01	-0.52787E-01
21	0.71965D 14	0.39925D 14	0.12960E 01	0.0	-0.55940E-01	-0.55330E-01
22	0.57273D 14	0.31791D 14	0.96714E 00	0.0	-0.58332E-01	-0.57721E-01
23	0.38706D 14	0.21762D 14	0.74704E 00	0.0	-0.60583E-01	-0.59972E-01
24	0.15502D 14	0.21161D 14	0.0	0.0	0.0	0.0
25	0.14543D 13	0.78610D 13	0.0	0.0	0.0	0.0
26	0.13524D 12	0.11281D 13	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
AVER.	0.39344D 14	0.22147D 14	0.15625E 03		-0.41580E-01	-0.41007F-01

TIME 0.0 POWER RATIO 0.10000E 01

POWER 0.50000E 09 WATT PM1 0.39344D 14 PM2 0.22147D 14 PER 0.49120E-03 PINT 0.0

FLM1

0.6990E 12	0.1727E 14	0.4902E 14	0.7647E 14	0.5953E 14	0.3114E 13

FLM2

0.1337E 13	0.9136E 13	0.2577E 14	0.4127E 14	0.3428E 14	0.6523E 13

AVPO

0.0	0.3322E 00	0.9378E 00	0.1497E 01	0.1233E 01	0.0

CRITICALITY SEARCH

KEFF SEARCH

SPRG = -0.10000E-01 DAPF = 0.10000E-01 LF = 50 ITCR = 1

ITERATIONS	PM2	REP	SPCR
24	22516D 14	0.40625E-02	-0.62471E-01

KEFF 1.066633

TIME 0.0 IT 0 POWER 0.50000E 09

	FLUX1	FLUX2	POWER	ROD VALUE	DKFBACK	DKVOID
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.41286D 11	0.44767D 12	0.0	0.0	0.0	0.0
3	0.44395D 12	0.28698D 13	0.0	0.0	0.0	0.0
4	0.47324D 13	0.65670D 13	0.22274E 00	0.0	0.28393E-02	0.0
5	0.11285D 14	0.62430D 13	0.28535E 00	0.0	0.25551E-02	0.0
6	0.17452D 14	0.95245D 13	0.41241E 00	0.0	0.21187E-02	0.0
7	0.24278D 14	0.13249D 14	0.55793E 00	0.0	0.75611E-03	-0.97804E-03
8	0.32161D 14	0.17561D 14	0.73493E 00	0.0	-0.11201E-02	-0.23779E-02
9	0.41669D 14	0.23064D 14	0.93310E 00	0.0	-0.36357E-02	-0.43311E-02
10	0.50971D 14	0.28601D 14	0.10970E 01	0.0	-0.66207E-02	-0.67050E-02
11	0.57320D 14	0.32186D 14	0.12020E 01	0.0	-0.98748E-02	-0.93341E-02
12	0.61273D 14	0.34428D 14	0.12722E 01	0.0	-0.15307E-01	-0.14532E-01
13	0.64146D 14	0.36085D 14	0.13493E 01	0.0	-0.21826E-01	-0.21007E-01
14	0.67926D 14	0.38771D 14	0.14315E 01	0.0	-0.28267E-01	-0.27400E-01
15	0.70415D 14	0.40783D 14	0.14530E 01	0.0	-0.34221E-01	-0.33341E-01
16	0.69059D 14	0.40044D 14	0.14086E 01	0.0	-0.39441E-01	-0.38587E-01
17	0.66032D 14	0.38318D 14	0.13490E 01	0.0	-0.43990E-01	-0.43170E-01
18	0.63246D 14	0.36738D 14	0.13175E 01	0.0	-0.48070E-01	-0.47268E-01
19	0.62153D 14	0.36631D 14	0.12963E 01	0.0	-0.51760E-01	-0.50971E-01
20	0.59659D 14	0.35680D 14	0.12032E 01	0.0	-0.54878E-01	-0.54144E-01
21	0.52633D 14	0.31503D 14	0.10185E 01	0.0	-0.57272E-01	-0.56650E-01
22	0.42363D 14	0.25371D 14	0.77998E 00	0.0	-0.58937E-01	-0.58466E-01
23	0.29922D 14	0.18219D 14	0.67559E 00	0.0	-0.60374E-01	-0.59972E-01
24	0.13667D 14	0.21024D 14	0.0	0.0	0.0	0.0
25	0.12821D 13	0.98559D 13	0.0	0.0	0.0	0.0
26	0.11923D 12	0.16503D 13	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
AVER.	0.37086D 14	0.22516D 14	0.15625E 03		-0.32583E-01	-0.32036E-01

	C1	C2	C3	C4	C5	C6
1	0.0	0.0	0.0	0.0	0.0	0.0

2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.50903D 10	0.13732D 11	0.33747D 10	0.25085D 10	0.19576D 09	0.26840D 08
5	0.10463D 11	0.28226D 11	0.69365D 10	0.51562D 10	0.40238D 09	0.55170D 08
6	0.15990D 11	0.43136D 11	0.10601D 11	0.78800D 10	0.61494D 09	0.84313D 08
7	0.22243D 11	0.60004D 11	0.14746D 11	0.10961D 11	0.85541D 09	0.11728D 09
8	0.29480D 11	0.79529D 11	0.19544D 11	0.14528D 11	0.11337D 10	0.15544D 09
9	0.38651D 11	0.10427D 12	0.25624D 11	0.19048D 11	0.14865D 10	0.20380D 09
10	0.47850D 11	0.12908D 12	0.31722D 11	0.23581D 11	0.18402D 10	0.25231D 09
11	0.53842D 11	0.14525D 12	0.35695D 11	0.26534D 11	0.20707D 10	0.28390D 09
12	0.57588D 11	0.15536D 12	0.38179D 11	0.28380D 11	0.22147D 10	0.30365D 09
13	0.60351D 11	0.16281D 12	0.40011D 11	0.29742D 11	0.23210D 10	0.31823D 09
14	0.64729D 11	0.17462D 12	0.42913D 11	0.31899D 11	0.24894D 10	0.34131D 09
15	0.67968D 11	0.18336D 12	0.45061D 11	0.33496D 11	0.26140D 10	0.35839D 09
16	0.66728D 11	0.18001D 12	0.44238D 11	0.32884D 11	0.25662D 10	0.35185D 09
17	0.63846D 11	0.17224D 12	0.42327D 11	0.31464D 11	0.24554D 10	0.33665D 09
18	0.61205D 11	0.16511D 12	0.40577D 11	0.30163D 11	0.23539D 10	0.32273D 09
19	0.60922D 11	0.16435D 12	0.40389D 11	0.30023D 11	0.23430D 10	0.32124D 09
20	0.59238D 11	0.15981D 12	0.39272D 11	0.29193D 11	0.22782D 10	0.31236D 09
21	0.52298D 11	0.14109D 12	0.34672D 11	0.25773D 11	0.20113D 10	0.27576D 09
22	0.42116D 11	0.11362D 12	0.27921D 11	0.20755D 11	0.16197D 10	0.22207D 09
23	0.30186D 11	0.81433D 11	0.20012D 11	0.14876D 11	0.11609D 10	0.15917D 09
24	0.16210D 11	0.43731D 11	0.10747D 11	0.79887D 10	0.62342D 09	0.85476D 08
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0

```
TIME     0.0      POWER RATIO     0.10000E 01

 POWER 0.50000E 09 WATT  PM1 0.37086D 14    PM2 0.22516D 14    PER 0.24615E 03    PINT 0.0
 FLM1
   0.9505E 12      0.2168E 14      0.5770E 14      0.6676E 14      0.4450E 14      0.2745E 13
 FLM2
   0.2200E 13      0.1228E 14      0.3244E 14      0.3872E 14      0.2792E 14      0.7339E 13
 AVPO
   0.0             0.4427E 00      0.1171E 01      0.1392E 01      0.9947E 00      0.0
```

STATIC CALCULATION

```
CHANNEL DATA
 HEIGHT      320.0 CM    SECTION      1.800 CM2   COOLANT DENSITY   0.73970 G/CM3   PRESSURE   70.0000 BAR
 INLET PIPE HEIGHT       15.0
 RISER 1 HEIGHT     20.0  RISER 2      0.0
 TOTAL CHANNEL POWER IN FUEL     0.50000E 05 WATT
 TOTAL CHANNEL POWER IN COOLANT 0.0          WATT

 IMPOSED EXIT QUALITY    0.09300

 INLET MASS FLOW 0.28913E 03 GR/SEC
 INLET VELOCITY /VINLET/=    217.15068 CM/SEC
 EXIT QUALITY /XOUT/=    0.09300
 AVERAGE VOID FRACTION /AVF/=    0.28144
```

```
POWER FLOW TO COOLANT /TPF/= 0.50000E 05 WATT.
POWER OUTPUT 0.49999E 05
INLET TEMPERATURE /TINLET/=    279.62

PRESSURE DROP      1.30880 BAR
 INLET        0.88287     CHANNEL      0.33426            RISER            0.09167
 FRICTION     1.07958     GRAVITY      0.18752            SPACE ACCEL.     0.04170

HEAT TRANSFER CONSTANTS
  HC 0.18157E 01          HB 0.23123E-01                  TETA      2.70                  TETAF       4.66
  ZE        0.0           R1 0.0                          BANKOFF K 0.87352
```

I	POW	FI	Q	VF	TSUR	TICL	AVTF	TMAXF	TL
1	0.34804E 02	0.77471E 01	-0.20285E-01	0.0	0.28425E 03	0.28997E 03	0.36896E 03	0.42580E 03	0.27998E 03
2	0.44585E 02	0.99244E 01	-0.18650E-01	0.0	0.28592E 03	0.29325E 03	0.39444E 03	0.46725E 03	0.28045E 03
3	0.64439E 02	0.14344E 02	-0.16288E-01	0.0	0.28903E 03	0.29963E 03	0.44588E 03	0.55111E 03	0.28113E 03
4	0.87176E 02	0.19405E 02	-0.13092E-01	0.18850E-01	0.29102E 03	0.30535E 03	0.50321E 03	0.64557E 03	0.28169E 03
5	0.11483E 03	0.25561E 02	-0.88828E-02	0.43733E-01	0.29146E 03	0.31034E 03	0.57097E 03	0.75850E 03	0.28240E 03
6	0.14580E 03	0.32453E 02	-0.35383E-02	0.75286E-01	0.29190E 03	0.31588E 03	0.64678E 03	0.88488E 03	0.28327E 03
7	0.17140E 03	0.38153E 02	0.27448E-02	0.10993E 00	0.29217E 03	0.32036E 03	0.70938E 03	0.98929E 03	0.28429E 03
8	0.18782E 03	0.41807E 02	0.96302E-02	0.14477E 00	0.29232E 03	0.32321E 03	0.74948E 03	0.10562E 04	0.28541E 03
9	0.19879E 03	0.44249E 02	0.16918E-01	0.20587E 00	0.29241E 03	0.32510E 03	0.77628E 03	0.11009E 04	0.28580E 03
10	0.21082E 03	0.46928E 02	0.24646E-01	0.27208E 00	0.29251E 03	0.32718E 03	0.80567E 03	0.11500E 04	0.28580E 03
11	0.22367E 03	0.49787E 02	0.32846E-01	0.33008E 00	0.29261E 03	0.32939E 03	0.83703E 03	0.12023E 04	0.28580E 03
12	0.22704E 03	0.50537E 02	0.41169E-01	0.37921E 00	0.29264E 03	0.32997E 03	0.84526E 03	0.12160E 04	0.28580E 03
13	0.22009E 03	0.48990E 02	0.49237E-01	0.41960E 00	0.29258E 03	0.32878E 03	0.82830E 03	0.11877E 04	0.28580E 03
14	0.21078E 03	0.46918E 02	0.56964E-01	0.45299E 00	0.29251E 03	0.32717E 03	0.80557E 03	0.11498E 04	0.28580E 03
15	0.20585E 03	0.45822E 02	0.64510E-01	0.48156E 00	0.29247E 03	0.32632E 03	0.79353E 03	0.11297E 04	0.28580E 03
16	0.20254E 03	0.45084E 02	0.71935E-01	0.50644E 00	0.29244E 03	0.32575E 03	0.78544E 03	0.11162E 04	0.28580E 03
17	0.18800E 03	0.41849E 02	0.78827E-01	0.52714E 00	0.29232E 03	0.32324E 03	0.74994E 03	0.10570E 04	0.28580E 03
18	0.15914E 03	0.35424E 02	0.84661E-01	0.54309E 00	0.29206E 03	0.31823E 03	0.67942E 03	0.93931E 03	0.28580E 03
19	0.12187E 03	0.27128E 02	0.89129E-01	0.55446E 00	0.29165E 03	0.31169E 03	0.58830E 03	0.78732E 03	0.28580E 03
20	0.10556E 03	0.23497E 02	0.92999E-01	0.56377E 00	0.29145E 03	0.30881E 03	0.54839E 03	0.72077E 03	0.28580E 03

RISER1 VF= 0.56377

FUEL TEMPERATURE MAP

1	425.80	391.74	366.81	342.37	318.10
2	467.25	423.62	391.68	360.38	329.28
3	551.11	488.05	441.89	396.65	351.70
4	645.57	560.26	497.81	436.61	375.80
5	758.50	646.13	563.86	483.24	403.14
6	884.88	742.20	637.75	535.39	433.70
7	989.29	821.55	698.76	578.42	458.87
8	1056.19	872.39	737.85	605.98	474.98
9	1100.91	906.37	763.96	624.40	485.74
10	1149.96	943.65	792.62	644.60	497.54
11	1202.29	983.41	823.18	666.15	510.13
12	1216.03	993.85	831.20	671.80	513.44
13	1187.71	972.33	814.67	660.14	506.63
14	1149.78	943.51	792.51	644.53	497.50
15	1129.70	928.26	780.79	636.26	492.67
16	1116.20	917.99	772.90	630.70	489.42
17	1056.96	872.98	738.30	606.30	475.16
18	939.31	783.58	669.57	557.84	446.83
19	787.32	668.06	580.75	495.19	410.18
20	720.77	617.47	541.85	467.74	394.11

TIME 0.0 SEC

POWER 0.50000E 05 PRESSURE 0.70000E 02 THF 0.50000E 05 AVF 0.28144 XOUT 0.09300

VINLET 217.151 PDROP 1.309 TINLET 279.617

AVERAGE FUEL TEMPERATURE 671.611

MAX.FUEL TEMP. 1216.027 IN NODE   12
MAX.CLAD TEMP.   329.974 IN NODE   12
MAX.HEAT FLUX   50.537 IN NODE   12

FIRST BOILING NODE   4

DYNAMIC CALCULATION

OPTIONS

VINLET IMPOSED
FUNCTION TYPE 0
COEFF. 0.0 0.0 0.0 0.0 0.0 0.0

PRESSURE
FUNCTION TYPE 0
COEFF. 0.0 0.0 0.0 0.0 0.0 0.0

INLET ENTHALPY
FUNCTION TYPE 4
TIME TABLE
TIMES 0.0 5.0000
VALUES 1.000000 0.980000

TIME STEP FOR THERMAL CALCULATION 0.5000E-01

POISON ABSORPTION PERTURBATION
EPITHERMAL TO THERMAL CROSS SECTION RATIO 0.0
DISTRIBUTED PERTUBATION
WEIGHTS IN REGIONS
0.0 0.0 0.0 0.0 0.0 0.0

PERTURBATION TIME TABLE
TIMES
0.0 0.0
VALUES
0.0

```
  TO =    0.010           VBAR = 0.0

TIME     0.2000  POWER RATIO     0.10004E 01
 POWER 0.50019E 09 WATT  PM1 0.37100D 14    PM2 0.22524D 14    PER 0.86135E 02    PINT 0.10002E 05

TIME     0.4000  POWER RATIO     0.10029E 01
 POWER 0.50146E 09 WATT  PM1 0.37196D 14    PM2 0.22581D 14    PER 0.12903E 02    PINT 0.20014E 05

TIME       0.500 SEC
   POWER 0.50253E 05  PRESSURE 0.70000E 02       THF 0.50035E 05      AVF    0.28127       XOUT    0.09304
   VINLET    217.151      PDROP      1.308      TINLET    279.149
  AVERAGE FUEL TEMPERATURE     671.634
  MAX.FUEL TEMP.  1216.066   IN NODE     12
  MAX.CLAD TEMP.   329.978   IN NODE     12
  MAX.HEAT FLUX     50.541   IN NODE     12
  FIRST BOILING NODE     4

TIME     0.6000  POWER RATIO     0.10128E 01
 POWER 0.50642E 09 WATT  PM1 0.37566D 14    PM2 0.22801D 14    PER 0.42884E 01    PINT 0.30082E 05

TIME     0.8000  POWER RATIO     0.10353E 01
 POWER 0.51763E 09 WATT  PM1 0.38401D 14    PM2 0.23300D 14    PER 0.23306E 01    PINT 0.40307E 05

TIME       1.000 SEC
   POWER 0.53243E 05  PRESSURE 0.70000E 02       THF 0.50173E 05      AVF    0.27947       XOUT    0.09294
   VINLET    217.151      PDROP      1.305      TINLET    278.682
  AVERAGE FUEL TEMPERATURE     672.169
  MAX.FUEL TEMP.  1216.956   IN NODE     12
  MAX.CLAD TEMP.   330.084   IN NODE     12
  MAX.HEAT FLUX     50.677   IN NODE     12
  FIRST BOILING NODE     4
```

TIME 1.0000 POWER RATIO 0.10711E 01

POWER 0.53555E 09 WATT PM1 0.39731D 14 PM2 0.24100D 14 PER 0.17300E 01 PINT 0.50825E 05

TIME 1.00001 IT 100 POWER 0.53555E 09

	FLUX1	FLUX2	POWER	ROD VALUE	DKFBACK	DKVOID
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.44242D 11	0.47967D 12	0.0	0.0	0.0	0.0
3	0.47573D 12	0.30750D 13	0.0	0.0	0.0	0.0
4	0.50712D 13	0.70370D 13	0.22284E 00	0.0	0.32661E-02	0.0
5	0.12092D 14	0.66898D 13	0.28547E 00	0.0	0.29422E-02	0.0
6	0.18702D 14	0.10206D 14	0.41264E 00	0.0	0.24665E-02	0.0
7	0.26021D 14	0.14200D 14	0.55846E 00	0.0	0.10340E-02	-0.10228E-02
8	0.34488D 14	0.18832D 14	0.73621E 00	0.0	-0.87712E-03	-0.24252E-02
9	0.44727D 14	0.24757D 14	0.93587E 00	0.0	-0.34033E-02	-0.43532E-02
10	0.54793D 14	0.30746D 14	0.11022E 01	0.0	-0.64187E-02	-0.67283E-02
11	0.61750D 14	0.34674D 14	0.12109E 01	0.0	-0.97012E-02	-0.93586E-02
12	0.66217D 14	0.37204D 14	0.12849E 01	0.0	-0.14261E-01	-0.13485E-01
13	0.69465D 14	0.39073D 14	0.13636E 01	0.0	-0.20947E-01	-0.20126E-01
14	0.73508D 14	0.41954D 14	0.14444E 01	0.0	-0.27554E-01	-0.26685E-01
15	0.76021D 14	0.44028D 14	0.14621E 01	0.0	-0.33655E-01	-0.32774E-01
16	0.74308D 14	0.43087D 14	0.14123E 01	0.0	-0.38998E-01	-0.38142E-01
17	0.70772D 14	0.41068D 14	0.13471E 01	0.0	-0.43646E-01	-0.42826E-01
18	0.67506D 14	0.39212D 14	0.13103E 01	0.0	-0.47807E-01	-0.47005E-01
19	0.66085D 14	0.38949D 14	0.12848E 01	0.0	-0.51564E-01	-0.50774E-01
20	0.63231D 14	0.37816D 14	0.11892E 01	0.0	-0.54735E-01	-0.54000E-01
21	0.55645D 14	0.33306D 14	0.10045E 01	0.0	-0.57168E-01	-0.56546E-01
22	0.44699D 14	0.26771D 14	0.76792E 00	0.0	-0.58862E-01	-0.58391E-01
23	0.31527D 14	0.19196D 14	0.66427E 00	0.0	-0.60322E-01	-0.59920E-01
24	0.14387D 14	0.22132D 14	0.0	0.0	0.0	0.0
25	0.13496D 13	0.10374D 14	0.0	0.0	0.0	0.0
26	0.12551D 12	0.17370D 13	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
AVER.	0.39731D 14	0.24100D 14	0.16736E 03		-0.31930E-01	-0.31431E-01

TIME 1.2000 POWER RATIO 0.11168E 01

POWER 0.55843E 09 WATT PM1 0.41429D 14 PM2 0.25123D 14 PER 0.15945E 01 PINT 0.61754E 05

TIME 1.4000 POWER RATIO 0.11671E 01

POWER 0.58357E 09 WATT PM1 0.43294D 14 PM2 0.26249D 14 PER 0.16883E 01 PINT 0.73170E 05

```
TIME      1.500 SEC
  POWER 0.59283E 05  PRESSURE 0.70000E 02       THF 0.50696E 05      AVF   0.27699      XOUT   0.09227

   VINLET   217.151     PDROP     1.305     TINLET   278.215

  AVERAGE FUEL TEMPERATURE    674.350
  MAX.FUEL TEMP.  1220.686  IN NODE   12
  MAX.CLAD TEMP.   330.528  IN NODE   12
  MAX.HEAT FLUX    51.249  IN NODE   12

  FIRST BOILING NODE    4


TIME    1.6000  POWER RATIO    0.12160E 01

 POWER 0.60801E 09 WATT  PM1 0.45107D 14    PM2 0.27344D 14    PER 0.21143E 01    PINT 0.85089E 05


TIME    1.8000  POWER RATIO    0.12558E 01

 POWER 0.62792E 09 WATT  PM1 0.46583D 14    PM2 0.28236D 14    PER 0.32410E 01    PINT 0.97458E 05


TIME      2.000 SEC
  POWER 0.64183E 05  PRESSURE 0.70000E 02       THF 0.51614E 05      AVF   0.27635      XOUT   0.09199

   VINLET   217.151     PDROP     1.307     TINLET   277.748

  AVERAGE FUEL TEMPERATURE    678.336
  MAX.FUEL TEMP.  1227.752  IN NODE   12
  MAX.CLAD TEMP.   331.308  IN NODE   12
  MAX.HEAT FLUX    52.259  IN NODE   12

  FIRST BOILING NODE    4

TIME    2.0000  POWER RATIO    0.12863E 01

 POWER 0.64313E 09 WATT  PM1 0.47712D 14    PM2 0.28916D 14    PER 0.50260E 01    PINT 0.11018E 06



  TIME   2.00001   IT     200    POWER    0.64313E 09
```

	FLUX1	FLUX2	POWER	ROD VALUE	DKFBACK	DKVOID
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.52003D 11	0.56384D 12	0.0	0.0	0.0	0.0
3	0.55918D 12	0.36146D 13	0.0	0.0	0.0	0.0
4	0.59608D 13	0.82716D 13	0.21819E 00	0.0	0.37252E-02	0.0

5	0.14222D 14	0.78682D 13	0.27977E 00	0.0	0.33937E-02	0.0
6	0.22018D 14	0.12017D 14	0.40490E 00	0.0	0.29078E-02	0.0
7	0.30679D 14	0.16743D 14	0.54894E 00	0.0	0.13687E-02	-0.11391E-02
8	0.40744D 14	0.22249D 14	0.72550E 00	0.0	-0.63444E-03	-0.26346E-02
9	0.52994D 14	0.29335D 14	0.92549E 00	0.0	-0.32077E-02	-0.45951E-02
10	0.65182D 14	0.36579D 14	0.10952E 01	0.0	-0.62949E-02	-0.70283E-02
11	0.73876D 14	0.41487D 14	0.12115E 01	0.0	-0.96529E-02	-0.97187E-02
12	0.79862D 14	0.44872D 14	0.12959E 01	0.0	-0.13173E-01	-0.12557E-01
13	0.84467D 14	0.47509D 14	0.13836E 01	0.0	-0.19250E-01	-0.18414E-01
14	0.89758D 14	0.51223D 14	0.14684E 01	0.0	-0.26139E-01	-0.25255E-01
15	0.92805D 14	0.53745D 14	0.14841E 01	0.0	-0.32498E-01	-0.31603E-01
16	0.90447D 14	0.52443D 14	0.14282E 01	0.0	-0.38052E-01	-0.37183E-01
17	0.85749D 14	0.49759D 14	0.13556E 01	0.0	-0.42868E-01	-0.42034E-01
18	0.81351D 14	0.47255D 14	0.13115E 01	0.0	-0.47163E-01	-0.46849E-01
19	0.79211D 14	0.46687D 14	0.12795E 01	0.0	-0.51030E-01	-0.50229E-01
20	0.75442D 14	0.45122D 14	0.11795E 01	0.0	-0.54285E-01	-0.53540E-01
21	0.66143D 14	0.39592D 14	0.99302E 00	0.0	-0.56777E-01	-0.56145E-01
22	0.52978D 14	0.31731D 14	0.75728E 00	0.0	-0.58506E-01	-0.58028E-01
23	0.37288D 14	0.22705D 14	0.65384E 00	0.0	-0.59993E-01	-0.59585E-01
24	0.16994D 14	0.26145D 14	0.0	0.0	0.0	0.0
25	0.15942D 13	0.12256D 14	0.0	0.0	0.0	0.0
26	0.14826D 12	0.20521D 13	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
AVER.	0.47712D 14	0.28916D 14	0.20098E 03		-0.31118E-01	-0.30698E-01

TIME 2.2000 POWER RATIO 0.12957E 01

POWER 0.64783E 09 WATT PM1 0.48078D 14 PM2 0.29114D 14 PER 0.15387E 01 PINT 0.12305E 06

TIME 2.4000 POWER RATIO 0.13355E 01

POWER 0.66777E 09 WATT PM1 0.49572D 14 PM2 0.29993D 14 PER 0.55959E 01 PINT 0.13616E 06

TIME 2.500 SEC
POWER 0.67397E 05 PRESSURE 0.70000E 02 THF 0.52615E 05 AVF 0.27357 XOUT 0.09332

VINLET 217.151 PDROP 1.304 TINLET 277.280

AVERAGE FUEL TEMPERATURE 683.124
MAX.FUEL TEMP. 1236.574 IN NODE 12
MAX.CLAD TEMP. 332.154 IN NODE 12
MAX.HEAT FLUX 53.355 IN NODE 12

FIRST BOILING NODE 4

I	POW	FI	Q	VF	TSUR	TICL	AVTF	TMAXF	TL
1	0.47831E 02	0.84520E 01	-0.28080E-01	0.0	0.28240E 03	0.28861E 03	0.37114E 03	0.42860E 03	0.27775E 03
2	0.61352E 02	0.10713E 02	-0.26086E-01	0.0	0.28422E 03	0.29210E 03	0.39736E 03	0.47085E 03	0.27832E 03
3	0.88837E 02	0.15315E 02	-0.23341E-01	0.0	0.28754E 03	0.29883E 03	0.45029E 03	0.55635E 03	0.27911E 03
4	0.12041E 03	0.20301E 02	-0.19825E-01	0.19368E-02	0.29127E 03	0.30630E 03	0.50962E 03	0.65274E 03	0.28008E 03
5	0.15880E 03	0.26852E 02	-0.15224E-01	0.32409E-01	0.29160E 03	0.31144E 03	0.57948E 03	0.76805E 03	0.28081E 03

6	0.20184E 03	0.34139E 02	-0.94210E-02	0.67377E-01	0.29195E 03	0.31718E 03	0.65774E 03	0.89720E 03	0.28175E 03
7	0.23778E 03	0.40181E 02	-0.26346E-02	0.10567E 00	0.29226E 03	0.32195E 03	0.72256E 03	0.10041E 04	0.28284E 03
8	0.26161E 03	0.44104E 02	0.47831E-02	0.14364E 00	0.29241E 03	0.32500E 03	0.76440E 03	0.10730E 04	0.28404E 03
9	0.27816E 03	0.46766E 02	0.12627E-01	0.18006E 00	0.29251E 03	0.32706E 03	0.79262E 03	0.11193E 04	0.28531E 03
10	0.29506E 03	0.49642E 02	0.20928E-01	0.24163E 00	0.29261E 03	0.32929E 03	0.82328E 03	0.11698E 04	0.28580E 03
11	0.31098E 03	0.52640E 02	0.29717E-01	0.30897E 00	0.29271E 03	0.33160E 03	0.85552E 03	0.12231E 04	0.28580E 03
12	0.31203E 03	0.53355E 02	0.38615E-01	0.36476E 00	0.29273E 03	0.33215E 03	0.86352E 03	0.12366E 04	0.28580E 03
13	0.29805E 03	0.51615E 02	0.47213E-01	0.40977E 00	0.29267E 03	0.33081E 03	0.84530E 03	0.12068E 04	0.28580E 03
14	0.28079E 03	0.49313E 02	0.55420E-01	0.44640E 00	0.29260E 03	0.32903E 03	0.82108E 03	0.11672E 04	0.28580E 03
15	0.26977E 03	0.48043E 02	0.63409E-01	0.47733E 00	0.29255E 03	0.32805E 03	0.80793E 03	0.11459E 04	0.28580E 03
16	0.26170E 03	0.47171E 02	0.71244E-01	0.50397E 00	0.29252E 03	0.32737E 03	0.79896E 03	0.11314E 04	0.28580E 03
17	0.24022E 03	0.43711E 02	0.78496E-01	0.52592E 00	0.29239E 03	0.32469E 03	0.76201E 03	0.10706E 04	0.28580E 03
18	0.20157E 03	0.36950E 02	0.84617E-01	0.54272E 00	0.29212E 03	0.31942E 03	0.68933E 03	0.95047E 03	0.28580E 03
19	0.15335E 03	0.28265E 02	0.89286E-01	0.55460E 00	0.29171E 03	0.31260E 03	0.59570E 03	0.79566E 03	0.28580E 03
20	0.13217E 03	0.24462E 02	0.93317E-01	0.56427E 00	0.29150E 03	0.30958E 03	0.55468E 03	0.72786E 03	0.28580E 03

RISER1 VF= 0.56416

TIME 2.6000 POWER RATIO 0.13749E 01

POWER 0.68743E 09 WATT PM1 0.51045D 14 PM2 0.30863D 14 PER 0.24195E 01 PINT 0.14970E 06

TIME 2.8000 POWER RATIO 0.14253E 01

POWER 0.71264E 09 WATT PM1 0.52925D 14 PM2 0.31984D 14 PER 0.28586E 01 PINT 0.16370E 06

TIME 3.000 SEC
POWER 0.72886E 05 PRESSURE 0.70000E 02 THF 0.53878E 05 AVF 0.27211 XOUT 0.09342

VINLET 217.151 PDROP 1.310 TINLET 276.813

AVERAGE FUEL TEMPERATURE 689.359
MAX.FUEL TEMP. 1248.154 IN NODE 12
MAX.CLAD TEMP. 333.195 IN NODE 12
MAX.HEAT FLUX 54.703 IN NODE 12

FIRST BOILING NODE 5

TIME 3.0000 POWER RATIO 0.14586E 01

POWER 0.72931E 09 WATT PM1 0.54166D 14 PM2 0.32728D 14 PER 0.16634E 02 PINT 0.17815E 06

TIME 3.00001 IT 300 POWER 0.72931E 09

FLUX1 FLUX2 POWER ROD VALUE DKFBACK DKVOID

To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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